REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
NPRDC TR 84-43

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
BIOMAGNETISM: POSSIBLE NEW PREDICTOR OF PERSONNEL PERFORMANCE

5. TYPE OF REPORT & PERIOD COVERED
Interim Report
FY 82-83

6. PERFORMING ORG. REPORT NUMBER
41-84-2/3

7. AUTHOR(s)
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8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Navy Personnel Research and Development Center
San Diego, California 92152

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
62715H
MIPR 83-507
600054

11. CONTROLLING OFFICE NAME AND ADDRESS
Navy Personnel Research and Development Center
San Diego, California 92152

12. REPORT DATE
June 1984

13. NUMBER OF PAGES
36

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Performance assessment
Magnetic fields
Biomagnetism
Evoked-potential
Personnel technology
Magnetoencephology

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objective of this effort was to determine whether biomagnetic recordings may prove effective in predicting personnel performance. Two experiments were conducted. In the first, bioelectric data (e.g., event-related brain potentials) and sample biomagnetic data (e.g., event-related fields) obtained from one individual were compared. Results suggest that biomagnetic recordings are more sensitive to biological activity localization than are bioelectric recordings.

In the second experiment, multiple serial recordings of visually evoked magnetic fields were taken on five people to obtain waveform topographic maps from the occipital and parietal brain regions. Waveform reliability was determined by signal averaging techniques and by examination of characteristic changes in waveform shape over the maps in comparison to background magnetic noise. The visually evoked field was found to be a multiphasic waveform composed of a short period sinusoidal deflection after about 200 msec. The waveform was observed in both the occipital and parietal regions lateral to the midline. Phase reversals of major deflections occurred between the left and right hemispheres and between the occipital and parietal regions of the right but not left hemisphere. The reliability of the visually evoked field components between 100 and 200 msec. should be adequate for their further use as a predictor of performance.

NPRDC TR 84-43

JUNE 1984

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NPRDC TR 84-43 June 1984

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FOREWORD

This research and development was conducted within task area B99QAXRA (Technology Development), work unit 98 3MR83-507 (54) (Biotechnology Predictors of Physical Security Personnel Performance), under the sponsorship of the Defense Nuclear Agency. The objective of the work unit is to determine the feasibility of using biotechnology procedures such as bioelectric and biomagnetic recordings from brain, heart, and muscle to improve predictions of physical security personnel reliability and performance effectiveness.

Earlier research in the area of biotechnology predictors of military personnel performance was funded under Independent Research and Independent Exploratory Development (IED) work units 042-04-03.02 (Measures of Averaged Evoked Cortical Potentials as Possible Predictors of Learning Potential and Performance) and 512-001-03.01 (Evaluation of Psychobiological Methods in the Screening and Selection of Naval Personnel) respectively and sponsored by the Director of Navy Laboratories. This research has been described in NPRDC TRs 77-13, 79-13, and 80-26 and TN 77-7 and summarized in TR 84-3. Research relating biotechnology predictors to potential applications in Navy training was conducted within task area ZF63-522-001, work unit 522-010-03.06 (Evaluating Evoked Potentials for Adaptive Instruction) and was described in NPRDC TRs 82-8, 83-11, and 83-16.

Previous reports written under the current work unit described the stress literature related to security guard personnel performance, experimental procedures for assessing performance under stress, and cerebral potential measures related to stress (NPRDC TN 83-9, SR 84-9, and TR 84-23). Also, TR 84-12 includes an article describing biophysical measures of visual fatigue. Work in this area was conducted under IED work unit ZR000-01-042.019.

Appreciation is expressed to Drs. R. Biersner, W. Black, E. Callaway, D. Crum, L. Kaufman, P. Naitoh, and D. Woodward for their helpful comments in reviewing an early draft of this report.

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SUMMARY

Problem and Background

The security of nuclear weapons is a primary concern of the Navy ship and shore community. Although handling and storing such weapons requires highly reliable personnel who are able to detect, identify, and respond to threats from a variety of sources, current procedures for predicting on-job performance of security personnel are not very effective.

Several years ago, this Center established a laboratory to explore the feasibility of developing and using a new technology to improve personnel assessment. One technology that has shown promise in predicting on-job performance better than techniques currently being used is the direct recording (eight contact electrodes on the scalp) of bioelectric brain wave activity, such as the event-related potential (ERP). Results obtained show that ERPs are related to cognitive processing and to performance of several Navy occupational groups, and have possible implication for Navy training programs. Recently, biomagnetic recording equipment was added to the laboratory.

Objective

The objective of this effort was to determine whether biomagnetism has the potential for predicting personnel performance.

Approach

Two experiments were conducted, which are described below.

1. Bioelectric (ERP) data and sample biomagnetic (event-related field (ERF)) data obtained from one individual were compared using white and color stimuli. Ongoing electrical and magnetic activity were averaged over 40 stimuli.

2. Five subjects were exposed to repeated flashes of a checkerboard pattern while the brain's electromagnetic responses were recorded using a superconducting quantum interference device (SQUID) associated with a second-order gradiometer pick-up coil arrangement located near the scalp's surface. Two hundred 1/2-second samples were averaged for each of 8 recording sites. The averaged waveform constituted the visually evoked magnetic response.

Results and Conclusions

1. Experiment I--It appears that biomagnetic recordings are more sensitive to biological activity localization than are bioelectric recordings.

2. Experiment II--The evoked fields were found to contain multiple deflections beginning at about 100 msec. after stimulation. The most consistent pattern was a sinusoid between 100 and 200 msec. Components after 200 msec. tended to be less reliable than earlier components. The amplitudes of components and their direction of deflection varied with location of the probe. Both the location of maximal activity and the pattern of activity changes with location varied between subjects.

Biomagnetic recordings are potentially effective predictors of on-job performance.

Future Direction

The results of the present study will be used in future research to identify components that may be subject to experimental treatments and brain processing regions associated with different brain functions. Further research can improve upon the present findings by increasing the signal-to-noise ratio of the recordings, recording simultaneously from several sites and integrating the data using topographic displays, and simplifying the stimulus conditions by using hemifield stimulation.

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INTRODUCTION

Problem

The security of nuclear weapons is a primary concern of the Navy ship and shore community. Handling and storing such weapons requires highly reliable security forces who are able to detect, identify, and respond to threats from a variety of sources (e.g., terrorist attack, disaffected crew members, or radical groups). Thus, there is a definite need for a method for predicting security guard performance effectiveness under baseline and stressful conditions that could greatly increase the reliability of nuclear security operations. Current physical security personnel assessment procedures are not adequate in predicting on-job performance.

Background

Bioelectric Recordings

Traditional personnel assessment procedures have depended heavily on paper-and-pencil tests. These measures have been successful for predicting school and training performance but not on-job performance. This shortcoming is undoubtedly due, at least in part, to the difficulty in defining job performance and in devising reliable and valid criterion measures. While continuing attention must be directed toward defining job performance, it is believed that concurrent research emphasizing "process" rather than "content" information will improve the prediction of job performance. To this end, this Center established a laboratory to explore the feasibility of developing and using a new technology to improve personnel assessment, including improved prediction of on-job performance and improved design and use of system equipment. One technology that has been demonstrated to be effective is bioelectric recordings obtained from brain activity.

Advances in understanding brain processes have provided procedures to assess individual differences and unique capabilities more accurately. Bioelectric measures, such as electroencephalograms (EEGs) and brain event-related potentials (ERPs), are very small signals recorded from electrodes attached to the scalp. EEGs show ongoing brain activity, while ERPs show activity after a sensory system (i.e., vision or hearing) has been stimulated (e.g., by light flashes or clicks to the ears). Brain processing assessed through ERP procedures may provide more accurate predictions of human performance than do methods currently being used by the Navy. During ERP recordings, electrodes are placed in contact with the scalp over predetermined sites (see Figure 1) in the frontal (a secondary association area, F3 and F4), temporal (auditory reception, T3 and T4), parietal (association area, P3 and P4), and occipital (visual reception, O1 and O2) regions of the left and right hemispheres (LHs and RHs) (Jasper, 1958). They are referenced to the nose, while the subject ground is at Pz. Data collection procedures used in the Center's ERP projects are described in Lewis (1983b).

Results of these projects have shown that ERP measures are related to various measures of academic and job performance. Visual ERP activity is related to success or failure in a Navy remedial reading program (Lewis, Rimland, & Callaway, 1976); Navy paper-and-pencil aptitude test scores (Lewis, Rimland & Callaway, 1977); cognitive information processing (Lewis, Federico, Froning, & Calder, 1981); sensory interaction, distractability, and reading ability (Lewis & Froning, 1981); pilot and radar intercept officer performance (Lewis, 1979; Lewis & Rimland, 1979); sonar operator performance (Lewis, Rimland, & Callaway, 1978; Lewis & Rimland, 1980); and recruit promotion rate and attrition (Lewis, 1983a, 1983b). In addition, results suggested implications for display/console design (Lewis, 1983b) and application to security guard personnel (Lewis, 1981, 1983c). Recently, the Center's laboratory was substantially augmented by the addition of the capability for biomagnetic recording, in which a very small magnetic output is recorded from biological tissue.

Biomagnetic Recordings

One recently published volume covers superconducting technology (Schwartz & Foner, 1983) and three cover biomagnetism (Erné, Hahlbohm, & Lubbig, 1981; Romani & Williamson, 1983; Williamson, Romani, Kaufman, & Modena, 1983). Reviews of biomagnetism rationale and methodology may be found in Kaufman and Williamson (1982); Reite and Zimmerman (1978); Williamson and Kaufman (1980, 1981a, 1981b); Williamson, Kaufman, and Brenner (1977); Sarwinski (1977); and Swithenby (1980). Biomagnetic recordings have been made from (1) the heart (magnetocardiogram--MCG) (Cohen, 1967; Cohen & Chandler, 1969; Cohen & MacArthur, 1974; Cohen & Jost, 1974; Cohen & Kaufman, 1975; Cohen, Edelsack & Zimmerman, 1970; Wikswo, Malmivuo, Barry, Crawford, Fairbank, Giffard, Harrison, & Roy, 1975), (2) muscle tissue (magnetomyogram--MMG) (Cohen & Givler, 1972), (3) magnetic dust from the lungs (Cohen, 1973; Cohen, Arai, & Brain, 1979), and (4) the brain (magnetoencephalogram--MEG; magnetic event-related field--MERF).

Magnetic output from the brain has been observed and compared with ongoing EEG activity (Cohen, 1968, 1972; Reite, Zimmerman, Edrich, & Zimmerman, 1976; Hughes, Hendrix, Cohen, Duffy, Mayman, Scholl, & Cuffin, 1976). Recently, magnetic fields have been observed from nerve action potential (Wikswo & Barach, & Freeman, 1980). Sensory stimulation has provided a stimulus-locked event-related brain activity (Brenner, Kaufman, & Williamson, 1977; Williamson, Kaufman, & Brenner, 1979) for visual stimuli (Teyler, Cuffin, & Cohen, 1975; Brenner, Williamson, & Kaufman, 1975; Williamson, Kaufman, & Brenner, 1978; Zimmerman, Edrich, Zimmerman, & Reite, 1978; Brenner, Okada, Maclin, Williamson, & Kaufman, 1981; Okada, Kaufman, Brenner, & Williamson, 1982); auditory stimuli (Reite, Edrich, Zimmerman, & Zimmerman, 1978; Farrell, Tripp, Norgren, & Teyler, 1980; Reite, Zimmerman, & Zimmerman, 1981a, 1981b; Zimmerman, Reite, & Zimmerman, 1981; Romani, Williamson, & Kaufman, 1982); and somatosensory stimuli (Brenner, Lipton, Kaufman, & Williamson, 1978; Williamson & Kaufman, 1980). Kaufman, Okada, and Brenner (1981) compared somatosensory evoked fields and potentials and discussed theoretical and experimental evidence to suggest that biomagnetic data may complement the bioelectric data. They suggested that bioelectric activity is associated with volume currents conducted through extracellular fluid, which may contribute to spreading volley activity over much of the brain area. Biomagnetic activity, however, presumably originates from intracellular currents in the axonal region of the neuron. Unlike bioelectric activity, biomagnetic activity appears transparent to varying tissue density and interfaces.

Objective

The objective of this effort was to determine whether biomagnetism can potentially be used for predicting personnel performance.

Hypothesis

It was hypothesized that the inductance technique of recording the electromagnetic fields from brain tissue would provide (1) greater definition of source activity (Lewis, 1983a), and (2) information not readily observable with ERP measurement techniques (Cohen, 1972). Greater definition of source activity is expected for the following reasons:

1. No direct contact with the body is required. Thus, artifacts found during traditional contact EEG/ERP recording, such as high impedance producing "noise" at the recording site, eye movement, or muscle activity, are minimized or eliminated.

2. The inductance technique is monopolar, which allows detection of absolute changes in the field strength in a localized area immediately below the probe.

3. The recorded ERF is due primarily to current flow within active tissue (intracellular) rather than to current flow within adjacent tissue (extracellular) exposed to the weak field of an active source (Cuffin & Cohen, 1977; Kaufman, Okada, & Brenner, 1981).

4. The recorded ERF is transparent to biological tissue and interfaces, which means that distance and orientation are the only factors affecting the change in field strength with change in probe location relative to the source.

The inductance technique is expected to provide additional information because an induced current occurs maximally when the coil of the inductance probe is placed parallel to the direction of source current flow; the maximal potential difference measured between two electrodes in ERP recording is registered when the voltage is measured across the direction of current flow. This results in a situation where the rate of change in the electromagnetic field is the same for both types of measures but the maxima of aplitudes are spatially located 90° apart. Because of the limited sensitivities of both types of measures, the location of each detector relative to direction of source current flow becomes critical for its measurement. The electromagnetic fields of the brain, of course, are due to many current sources with different orientations. In the cerebral cortex, where most of the sources are thought to reside (Elul, 1972; Cuffin & Cohen, 1979), the convolutions of cortical tissue orient some current sources perpendicular to the scalp surface and others parallel to it. Thus, an electric potential probe and an inductance probe, when placed on the same scalp location, should detect activity maximally from different current sources in the cortical tissue.

APPROACH

Instrumentation

Instrumentation used in the Center's ERP project is described in Lewis (1983b).

For early biomagnetic recordings, an expensive and large shielding facility was required (Cohen, 1967, 1970, 1975). The Center's biomagnetic measuring system is a second-derivative gradiometer, which allows recording of data without such shielding (S.H.E. Corporation, Model 330X). Basic operation of this type of system has been discussed in earlier papers (Brenner, Williamson, & Kaufman, 1975; Sarwinski, 1977; Williamson & Kaufman, 1981a; Kaufman, Okada, & Brenner, 1981). Briefly, the biomagnetic equipment is a cryogenic system, requiring liquid helium near absolute zero (4.2°K) for superconducting operation. During such operation, molecular action nearly stops, providing the required sensitivity for recording the extremely small biomagnetic activity. Biomagnetic activity is sensed by the pickup coil, one of three coils inside the cryogenic dewar (S.H.E. Corporation, Model BMD-5). The other two coils cancel the signals from distant sources, thus allowing recordings to be made without magnetic shielding. Currents in the three coils are inductively coupled to a superconducting quantum interference device (SQUID), which amplifies the signal and, using room temperature electronics (S.H.E. Corporation, Model 30), generates a change in output voltage proportional to the change in magnetic field. Output voltage of the SQUID electronics unit is passed to a standard AC amplifier (Grass P511J). Biomagnetic activity is monitored before (Tektronix 434, two channel oscilloscope) and after (Tektronix 5103N, eight channel oscilloscope) amplification. Typically, a gain of 50X is used for the MCG data while 100X is used for the MEG/MERF data.

Eight channels of EEG/ERP/MERF data can be input to the computer for sampling, digital filtering, averaging, processing, displaying, and storing the data. In Experiment I (see below), analog MEG data were low pass filtered at 10Hz; a 60 Hz notch filter at the SQUID electronics unit was also used. In Experiment II, the band pass was expanded to 1-40 Hz. Generally, all amplifiers nominally pass 0.1-100 Hz during data acquisition. Calibration is 208 x 10^{-15} Telsa (208 femtotesla, fT) for MEG/MERF data.

Procedure

Two experiments were conducted, which are described below.

Experiment I

Bioelectric (ERP) data and sample biomagnetic (ERF) data obtained from one individual were compared using white and color stimuli. When white stimuli were used, ERP data were recorded from conventional frontal (F3 and F4), temporal (T3), parietal (P3 and P4), and occipital (O1 and O2) sites referenced to the subject's nose (Figure 1). ERF data were recorded from a location midway between Oz and Pz (the site marked ERF in Figure 1). The visual stimuli were generated using the commercial fluorescent tube (GE model F8T5-CWUSA) and custom power supply described in Lewis (1983b). Stimuli were triggered by the computer with a luminance of about 69 cd/m^2. Background luminance was about 10 cd/m^2. They were presented aperiodically about every 2 seconds (1.0-3.0 sec.), with a duration of about 2 msec. The stimulus geometry was square, subtending about 5 degrees visual angle. On-going electrical and magnetic activity were averaged over 40 stimuli.

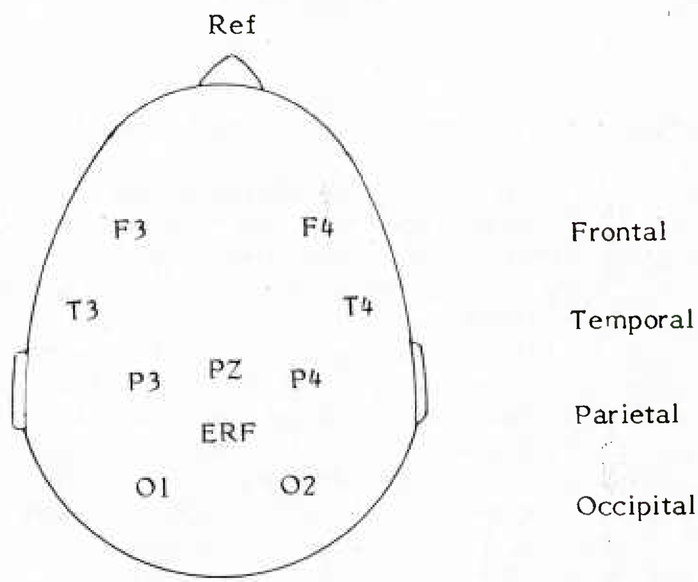

Figure 1. Bioelectric and biomagnetic recording sites. Data were not recorded from site T4 for this study.

When color stimuli were used, the same duration and presentation rates were used. However, the luminance intensities were approximately equated for all four colors a+ about 7 cd/m^2 and were presented in a darkened room. Wratten gelatin filters numbers 92, 93, and 94 were used for the red, green, and blue stimuli rspectively. The visual angle subtended about 5 degrees.

Experiment II

Data were collected from five experienced male subjects between the ages of 27 and 48. Subjects had normal or corrected vision during testing. Three subjects (Nos. 1, 2, and 3) were right-handed, and two (Nos. 4 and 5) were ambidextrous, one with a history of left-hand preference for writing.

Biomagnetic recording was accomplished in an unshielded room with the BMD-5 probe equipped with a second-order gradiometer and an r.f. SQUID sensor (S.H.E. Corporation, San Diego, CA). The BMD-5 output was bandpassed at 1-40 Hz through Krohn-Hite filters, amplified by a Grass P511J amplifier and processed on a NOVA 2/10 laboratory computer. The visual stimulus was a black-and-white checkerboard of 8mm squares with a spatial frequency of 8 cycles that subtended, in total, a visual angle of 7.2°. The checkerboard was back-illuminated by a fluorescent lamp of 2 msec. duration aperiodically, with a randomized interstimulus interval of 750 ± 150 msec. Stimulus intensity was about 69 cd/m^2 in a semidarkened room.

There were eight biomagnetic recording sites (see Figure 2), numbered according to a 28-location rectangular grid (the other 20 sites are not shown). Sites 02, 04, and 06 were located over the occipital region (the primary visual reception area), about 4 cm apart; sites 16, 18, 20, over the parietal region (the primary association area), about 4 cm anterior to sites 02, 04, and 06; and sites 10 and 12, midway between the occipital and parietal sites, about 2 cm lateral to the midline. Sites 04 and 18 were on the midline.

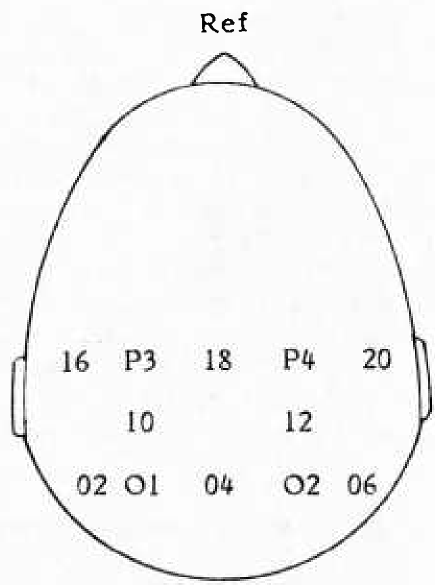

Figure 2. Biomagnetic recording sites. The relative positions of the parietal (P3 and P4) and occipital (O1 and O2) sites are given for reference.

During data acquisition, subjects were positioned prone on a polyfoam mattress so that their heads could be readjusted for the eight recording sites relative to the BMD-5 probe, which was kept in a fixed vertical position. The subjects were fitted with a lycra cap with the recording sites marked by eight adhesive electrode collars (2 cm diameter). The center of the BMD-5 probe (6 cm outside diameter, 2.36 cm coil diameter) was placed over each of the eight sites with the longitudinal axis of the gradiometer normal to the surface of the scalp. Subjects were instructed to (1) view the checkerboard binocularly and fixate on the center through a mirror located in their central visual field, and (2) count the number of stimulus presentations. A total of 200 trials were presented for each probe location, and the resulting waveforms were averaged over 512 msec. from stimulus onset. Background noise records were obtained by averaging the BMD-5 output under stimulus conditions without the subject in place. Noise records were taken before and after each subject's recording session.

RESULTS

Experiment I

Figure 3 shows seven channels of ERP data and one channel of ERF data obtained from the white visual stimuli. Amplitude standard deviation for the entire post-stimulus epoch appears with the associated mean value for each data channel. The negative mean values reflect a slight DC offset in the amplifiers. Maximum peak-to-peak amplitude was about 500 fT for the ERF data and about 25 μV for the ERP O1 and O2 sites. Between about 100 and 180 msec, the ERP and ERF signals appear to show a strong negative correlation, which is maximal at about 140 msec. However, a near zero cross-correlation was obtained between the full 512 msec ERP and ERF signals. Figure 4 provides an overlay of two channels of ERP data (from O1 and O2 sites) and the channel of ERF data from Figure 2. The similarity (high correlation) of the two ERP channels is evident, as is the dissimilarity between the ERP and ERF channels.

Figure 5 provides overlays of two channels of ERP data (from O1 and O2 sites) and the channel of ERF data obtained using color stimuli. As shown, the relationships between ERP and ERF data were maximally discrepant at about 150 msec for the white stimulus and at about 160-170 msec for the red, green, and blue stimuli. The large negative (ca. 150 msec) and positive (ca. 230 msec) ERP components have longer latency than do similar components seen in Figure 2 (ca. 130 and 200 msec), probably because of the differing dark adaptation conditions for the two data recordings. When looking at the general morphology of the ERF waveform, three major components appear for each of the three primary colors and seem to be "buried" within the white color record. A negative component may be seen for the red, green, and blue ERF records (ca. 110-120 msec) but not for the white record. At about 160 msec, a positive component may be seen, which increases in size from the red to green to blue ERF records but is barely observable in the white stimulus record. The large positive component in the red, green, and blue records (ca. 250 msec) appear delayed from the analogous component in the white record (ca. 170 msec).

The finding that ERF recordings have a greater sensitivity to source localization than do ERP recordings will probably clarify the color ERP findings of the White group (White, Kataoka, & Martin, 1977; White, White, & Hintze, 1979, 1982), who found specific temporal relationships among three sets of visual ERP (VERP) components that presumably reflect interactions among color processing and color perception under light-adapted conditions. It is often assumed that color processing in the occipital region is primarily cortical in nature. White et al. (1977) suggested that there may be considerable

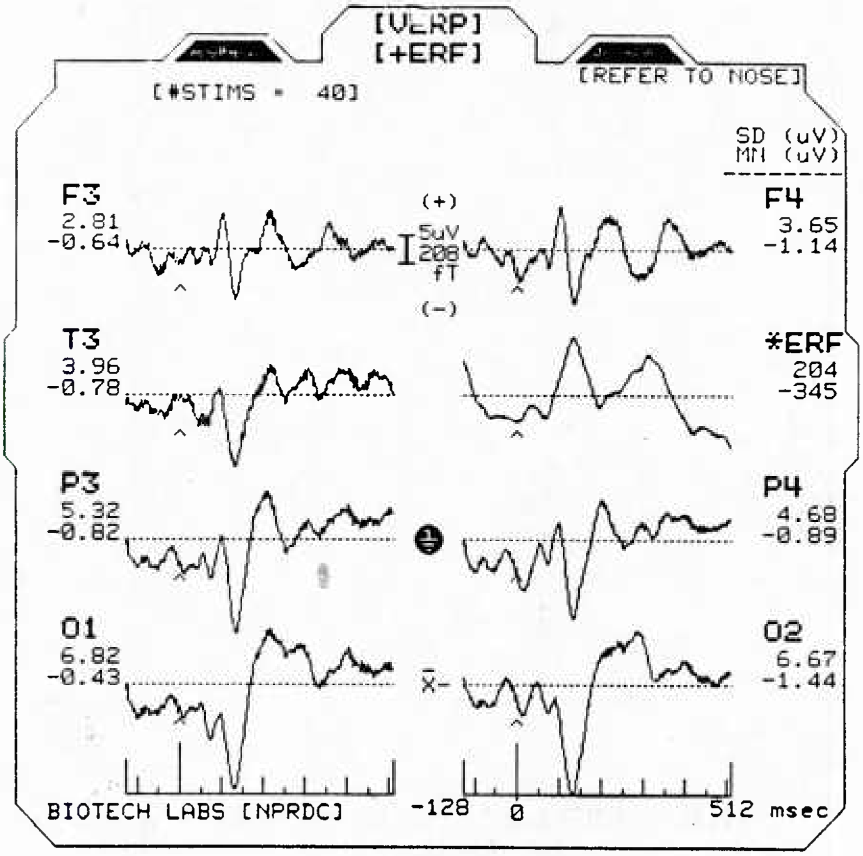

Figure 3. Visual event-related potentials and event-related field data: One subject's response averaged over 40 trials.

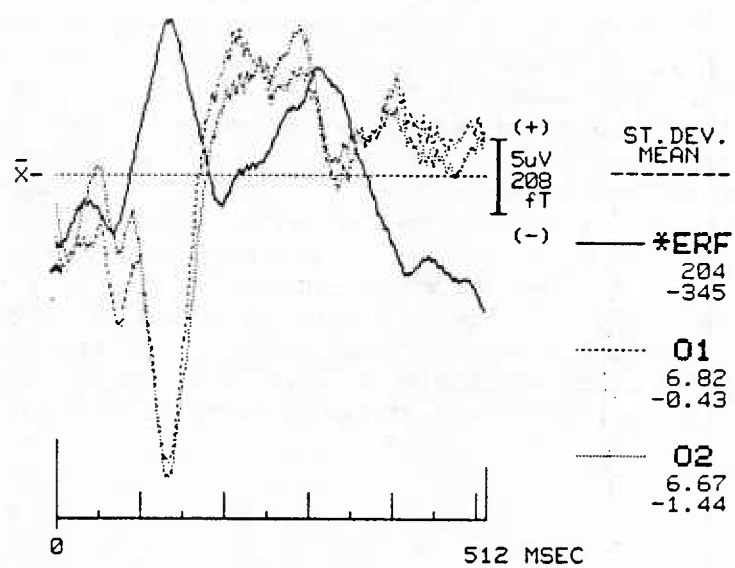

Figure 4. Overlay of two visual ERP records with ERF activity.

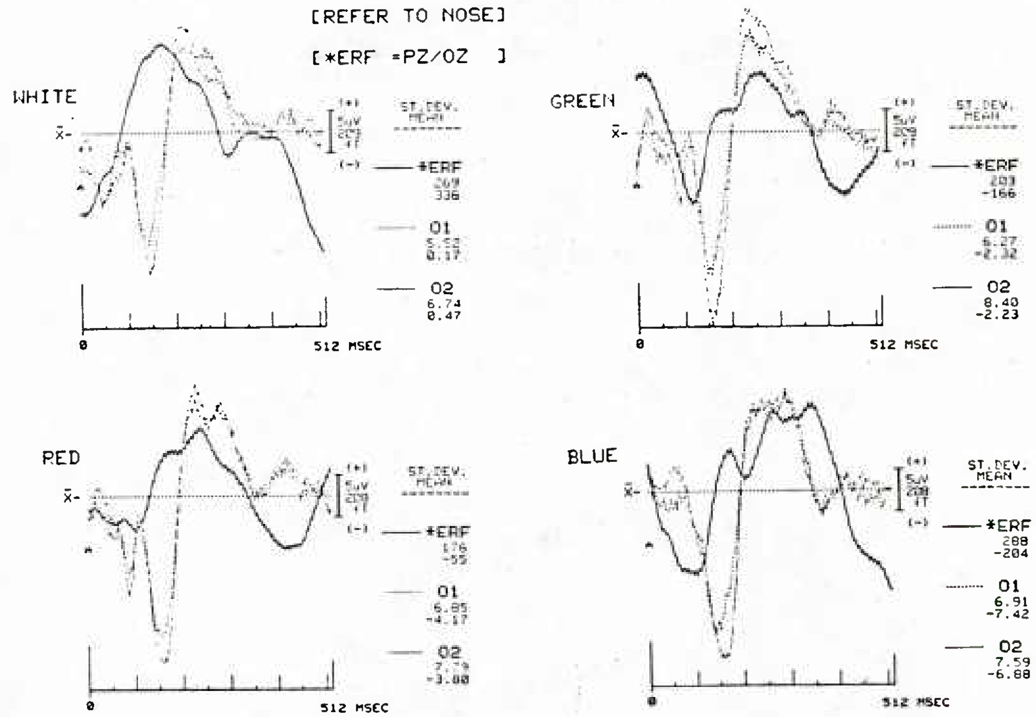

Figure 5. Overlay of ERP and ERF activity produced by four colors in one subject over 40 trials.

processing of visual information in subcortical areas. Perhaps such subcortical activity may be defined further through the biomagnetic approach. Recently, Okada, Kaufman, and Williamson (1983) described magnetic activity associated with the vertex P300 ERP complex and suggested that this complex may originate in the subcortical hippocampal region.

Figure 6 provides visual ERF data recorded from the O1 and O2 sites from white stimuli and averaged over 40 trials. A large positive component may be seen at about 130 msec at the O2 site and about 280 msec for the O1 site. Similar maximum-minimum amplitude relationships have been noted over the two hemispheres by Brenner et al. (1975) and Reite and Zimmerman (1978). Brenner et al. (1975) noted that the amplitude reversal occurred about 5 cm from the midline, whereas Figure 6 shows that this reversal occurred at from 1 to 2 cm. Such amplitude reversal may be due to the same current dipole source producing a field that exists from the left hemisphere and reenters the right hemisphere. Also, a comparison of the ERF recordings at sites O1 and O2 in Figure 6 with the ERP recordings at sites O1 and O2 in Figures 3 and 4 shows that ERF recordings have a greater sensitivity to localization of brain activity than do ERP recordings. Since increased sensitivity implies an increased ability to assess individual differences, it appears that ERF recordings may better predict on-job performance than will ERP recordings.

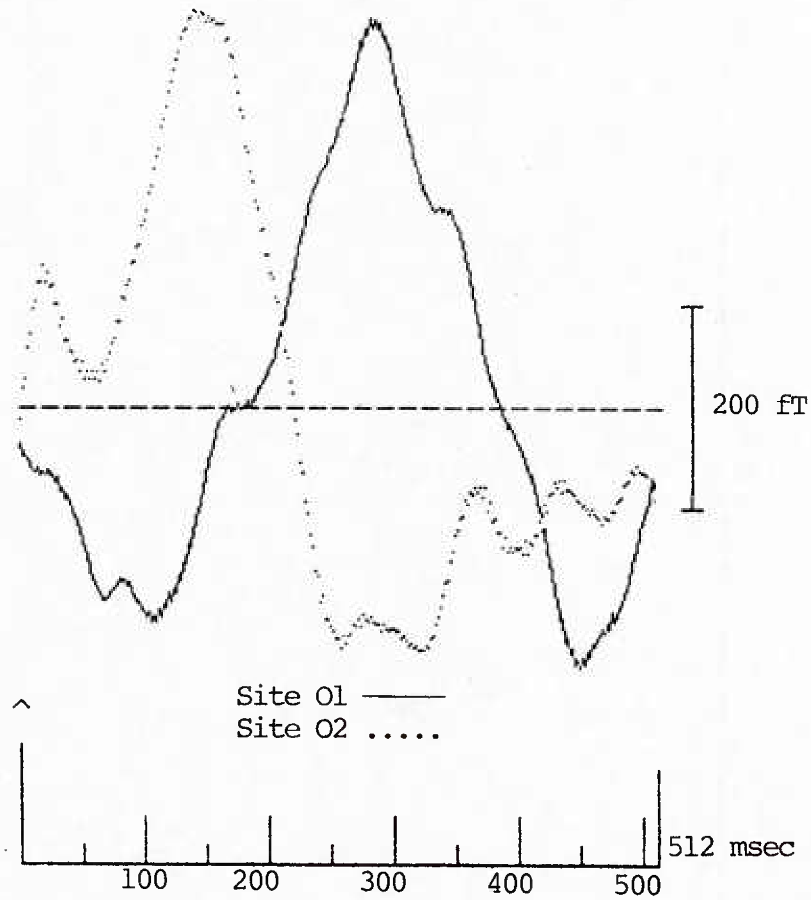

Figure 6. Visual ERF activity recorded from left and right occipital (O1 and O2) sites.

Experiment II

Figure 7 provides a waveform topographic map of the eight recording sites from subject 1. Peak-to-trough deflections greater than 200 fT were found for all recording sites of this subject, with the largest occurring before 200 msec. The deflections had shorter periods before 200 msec. than after. Phase reversals of components defined at equivalent latencies between left and right homologous locations are apparent before 200 msec. Similar results were obtained from the other four subjects. Topographic maps of these subjects are provided in the appendix.

The significance of waveform components and of phase reversals were estimated by comparisons with noise records as follows: The distributions of the largest peak-to-peak fluctuations within a record, and of the largest differences in peaks of opposite polarity between the first and second noise records (when overlaid) within a session at any equivalent latency were analyzed. Results demonstrated that, over the five pairs of averaged noise recordings, the peak-to-peak fluctuations and the differences in opposite peaks rarely exceeded 150 femtoTesla (fT) if the fluctuations were gaussian. Figure 8 presents an overlay of a pair of noise records taken before and after a subject's recording session.

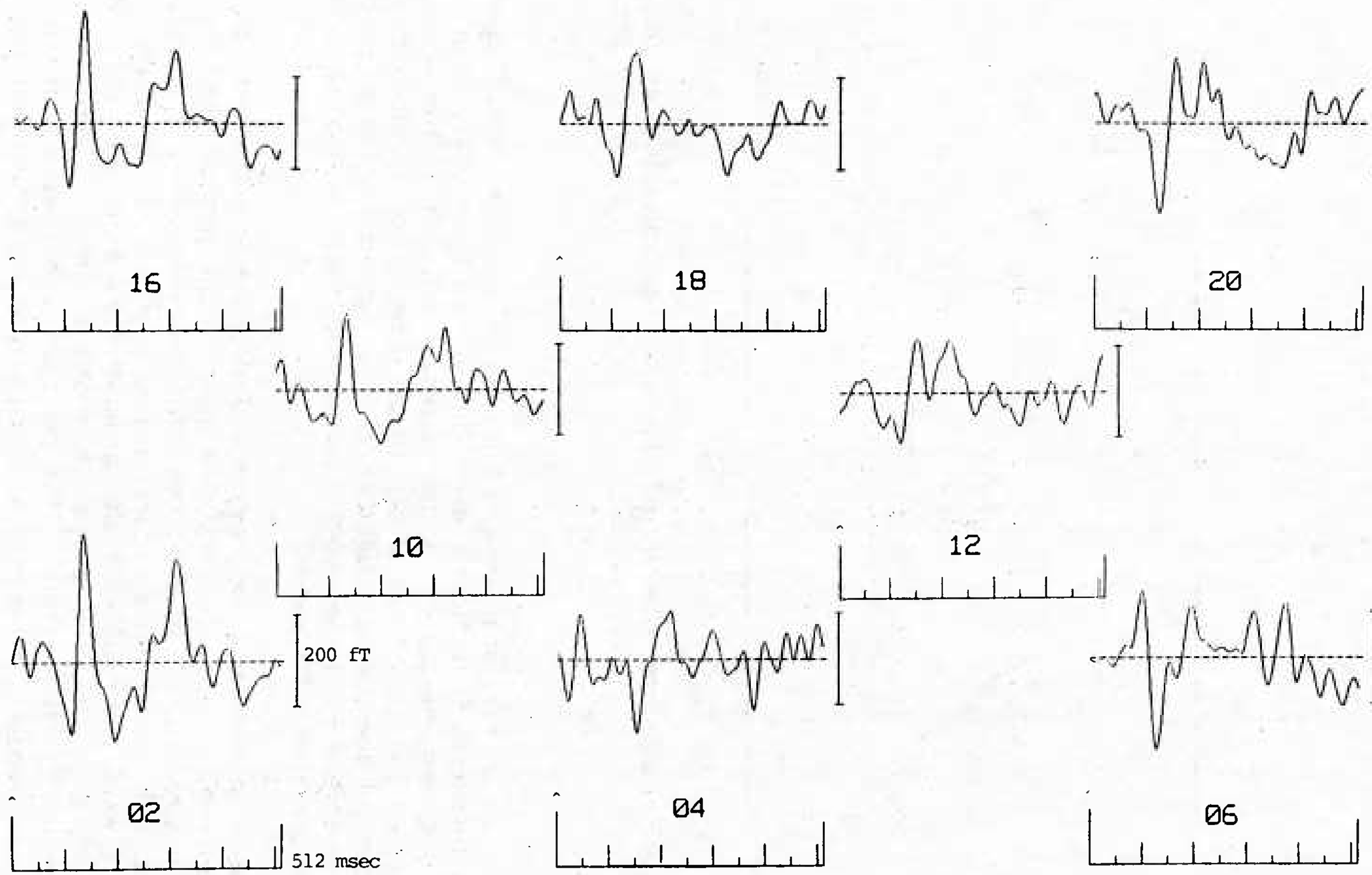

Figure 7. Map of visually evoked fields from subject 1.

Calibration is 200 fT on the ordinate and 100 msec/major division on the abscissa. Data were recorded serially among sites.

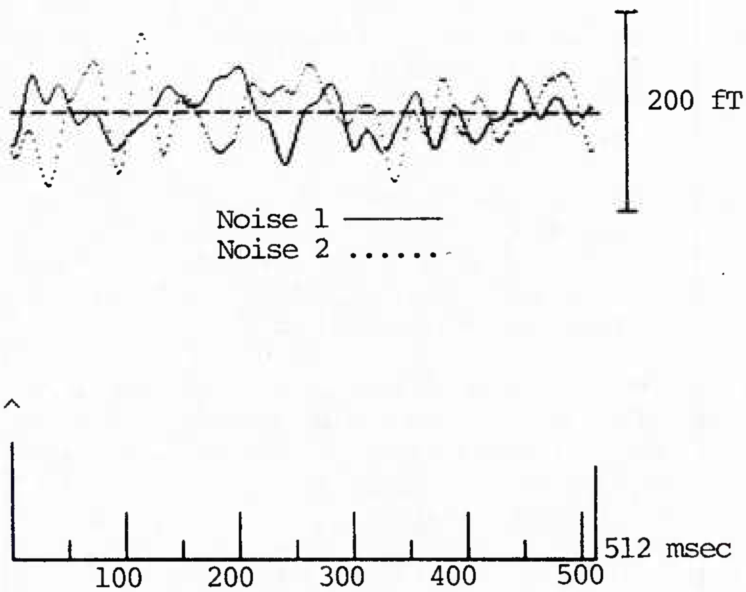

Figure 8. Noise recordings resulting from averages of 200 flashes triggered (at T=0) samples of BMD-5 output without subject. One noise record (#1) was taken before a subject run, and the other, afterwards.

Because the data recorded during subject runs included both nonbiological noise and biological ERF changes, the test described above established how large the ERF changes would have to be before they could be separated from changes due to noise contributions alone. Among single runs, the noise changes would be expected to exceed 150 fT only 5 percent of the time; thus, observed changes greater than 150 fT would most likely be of biological origin. Finding these changes within specific latency windows would increase the certainty of their biological validity.

Displacing the probe's location will change its orientation to the biological current source. This, in turn, will result in a change in the direction of the deflection (phase inversions) of the observed waveform if the induction coil was moved laterally from opposite sides of the current vector. However, the random contributions of noise from two records could, when overlaid, appear to represent a phase reversal. It was determined that differences between noise records greater than 150 fT would occur in only 1 percent of the comparisons under the existing noise conditions. Thus, the criterion of amplitude differences greater than 150 fT between two overlaid waveforms of simultaneous components progressing in opposite directions were applied to detect phase inversions that were indicative of probe reposition about a probable biological source.

Overlays of waveforms for various subjects are displayed in Figure 9 and described below.

1. Figure 9a compares waveforms from occipital sites 02 and 06 for subject 4. Note the apparent slowing of the oscillations (lengthening period) over the interval and

the 180 phase difference between the waveforms. Left/right phase reversals were observed between occipital locations for all subjects before 200 msec; and amplitude differences, for four subjects (all but No. 1) after 200 msec. The latencies at which these differences occurred varied among the subjects.

2. Figure 9b, which compares waveforms from sites 10 and 12 for subject 2, shows that differences occurred after 200 msec. This was also true for two other subjects (Nos. 1 and 5). However, since these amplitude differences were due to deflections in only one of the two locations of a pair, they cannot be interpreted as phase reversals at the latencies of occurrence between those locations.

3. Figure 9c, which compares waveforms from sites 16 and 20 (2 cm lateral to P3 and P4 respectively) for subject 3, shows that phase inversions occurred before 200 msec. and the recovery slopes differed through the remainder of the interval. Phase inversions between parietal locations were found for four subjects (all but No. 2) before 200 msec. and for four subjects (all but No. 4) after 200 msec.

Waveform differences between occipital and parietal sites were examined by comparisons within the hemispheres and on the midline. There were no significant differences between left occipital (site 02) and left parietal (site 16) waveforms within subjects except for subject 2 at 270 msec. Midline differences (site 04 vs. site 18) were observed for three subjects (Nos. 1, 4, and 5) at 150 msec. These same three subjects showed phase inversions before 200 msec. between occipital (site 06) and parietal (site 20) locations within the right hemisphere (RH). An example of the RH occipital/parietal phase inversion for subject 5 is given in Figure 10. No RH phase inversions were detected in subjects Nos. 2 and 3.

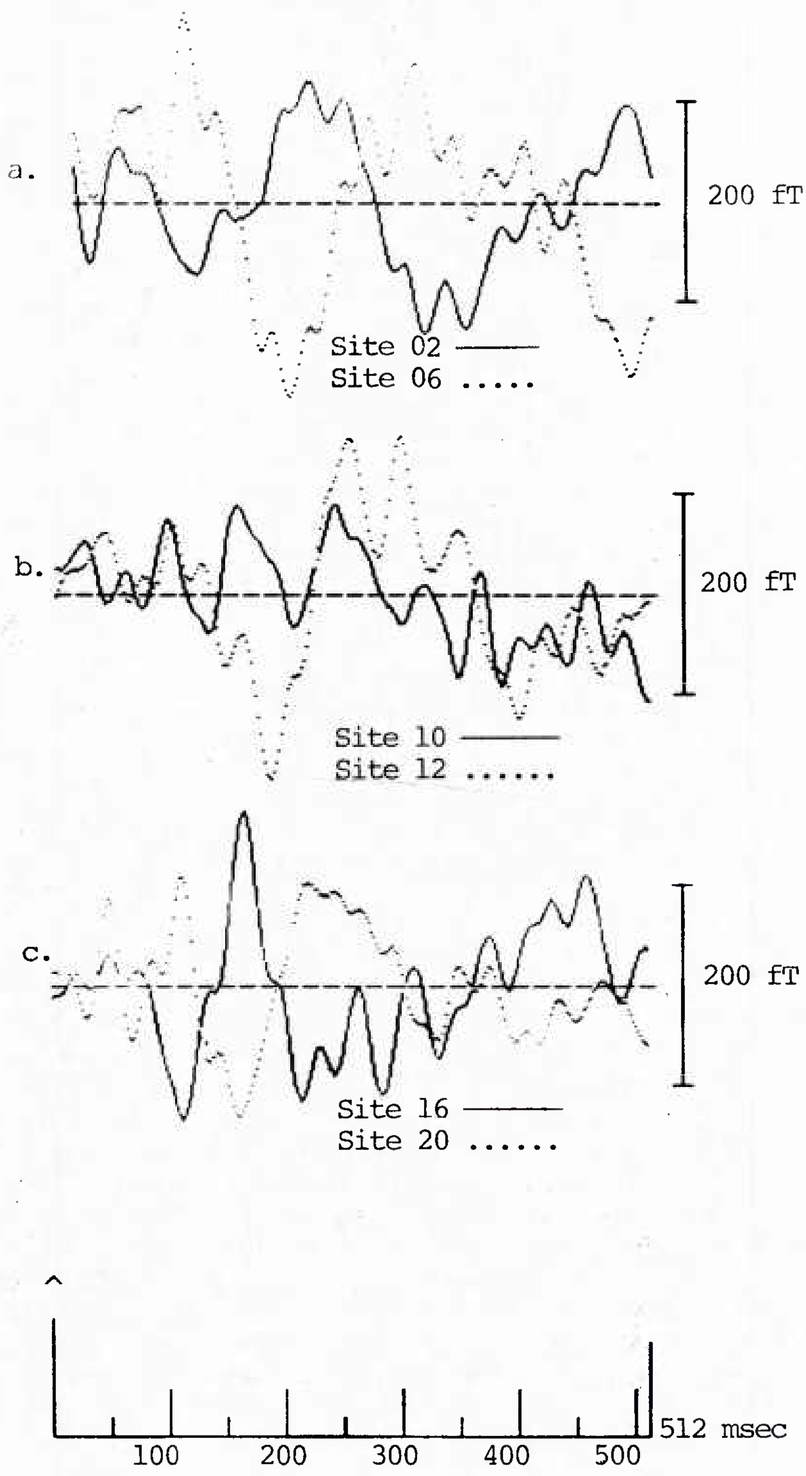

Figure 9. Comparison of waveforms for various subjects.

a. From sites 02 and 06 (left vs. right occipital) for subject 4.

b. From sites 10 and 12 (left vs. right occipitor-parietal) for subject 2.

c. From sites 16 and 20 (left vs. right parietal) for subject 3.

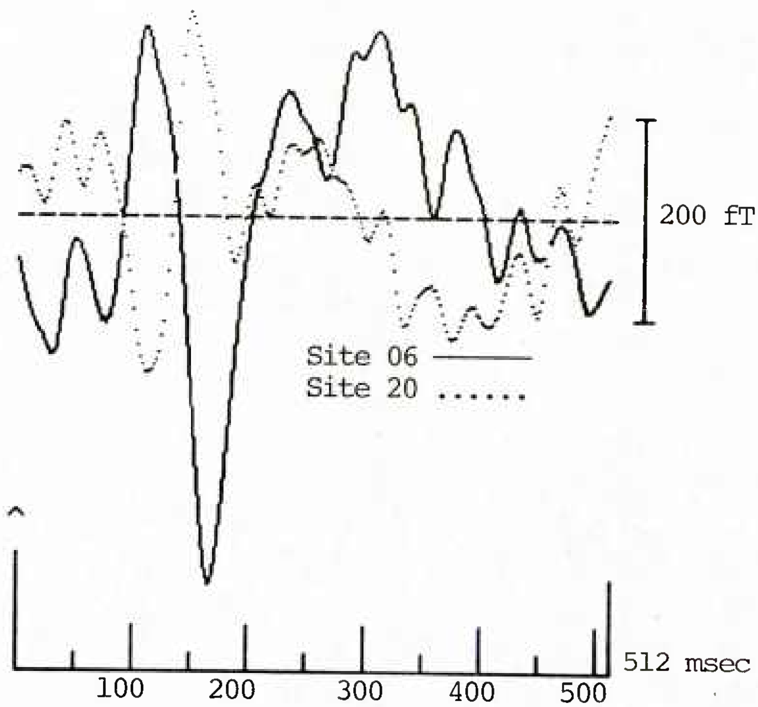

Figure 10. Waveforms from sites 06 and 20 (occipital vs. parietal, right hemisphere) for subject 5.

DISCUSSION

Under the conditions of Experiment II, the visually evoked field from the occipital region, 4 cm lateral to the midline, can be characterized as a multiphasic waveform composed of a short period sinusoidal deflection beginning around 100 msec. followed by a relatively longer period monophasic deflection after about 200 msec. The first major deflection recorded from left occipital sites is downward, initiating a "W" shaped pattern, while the first major deflection from right occipital sites is upward, beginning an "M" shaped pattern. Waveforms from parietal regions were similar to those from occipital regions except that phase reversals occurred within the RH. Differences in occipital-parietal phase inversions of the components between 100 and 200 msec. between left and right hemispheres in three of the subjects are interesting because they may reflect anatomical variations that relate to behavioral idiosyncracies (i.e., handedness). While handedness itself may be a relatively easily determined function, other talents that have neuroanatomical bases may be predicted by a more precise examination of the functional anatomy using noninvasive biomagnetic measures.

Previous descriptions of the visual evoked fields have included various components similar to the present findings. Teyler et al. (1975) examined the first 225 msec. following a flash stimulus and indicated by his calibrated figure that the first consistent deflection occurred around 80 msec. and developed into a 60 msec. period oscillation. Reite et al. (1976) signal averaged to unpatterned flash over 250 msec. and recorded a "W" shaped waveform at C3 with a period of about 83 msec. Zimmerman et al. (1978) found the evoked field in several sites and displayed an "M" shaped waveform with P4 with about

90 msec. period. Finally, Okada et al. (1983) presented a vertical grating pattern and averaged responses over 500 msec. They reported major left/right phase reversals after 250 msec. and a "W" shaped pattern in the left occipital region with a period of about 125 msec. The relative direction of the deflections of each of the waveforms (except for those reported by Teyler et al., 1975) are consistent with left to right phase reversals. If most authors represented the outward direction of the field from the scalp with an upward deflection of the waveform, then the common finding was a field that emerged from the RH starting at about 100 msec. while a field entered the left occipital region.

Richer, Barth, and Beatty (1983) conducted a study that was similar methodologically to the present (except that they used hemifield instead of full-field stimulation) but described different waveforms. They presented a 21-point map of the transient visual evoked field that included medial sites in the occipital and parietal regions. They found that phase inversions were related to visual hemifield of stimulation rather than to site of recording. Furthermore, phase changes between occipital and parietal locations were not observed, but reversals did occur with sites below the occipital line. Latencies of the major deflections were comparable to those previously reported. The differences between the results of the Experiment II and those of the Richer et al. study suggest that responses to full-field stimulation are not a linear sum of those to hemifield stimulation when recorded with biomagnetic induction techniques. These differences may be productively explored.

This experiment showed that the most consistent components of the transient visual evoked field between individual subjects occur from 100 to 200 msec. after stimulus onset. Activity following 200 msec. may be reliable within subjects, as evidenced by large averaged amplitudes, but is variable in morphology between subjects. The consistency of the early waveform under stable experimental conditions makes it suitable as a dependent variable for further studies of individual differences and as a response measure to change in experimental conditions.

FUTURE DIRECTION

The results of this research have advanced knowledge of the shape of the visual ERF, its reliability, and its spatial distribution. The results will be used in future studies to identify components that may be subject to experimental treatments, and to locate brain processing regions associated with different brain functions. Further research can improve upon the present findings by increasing the signal-to-noise ratio of the recordings, recording simultaneously from several sites and integrating the data using topographic displays, and simplifying the stimulus conditions by using hemifield stimulation.

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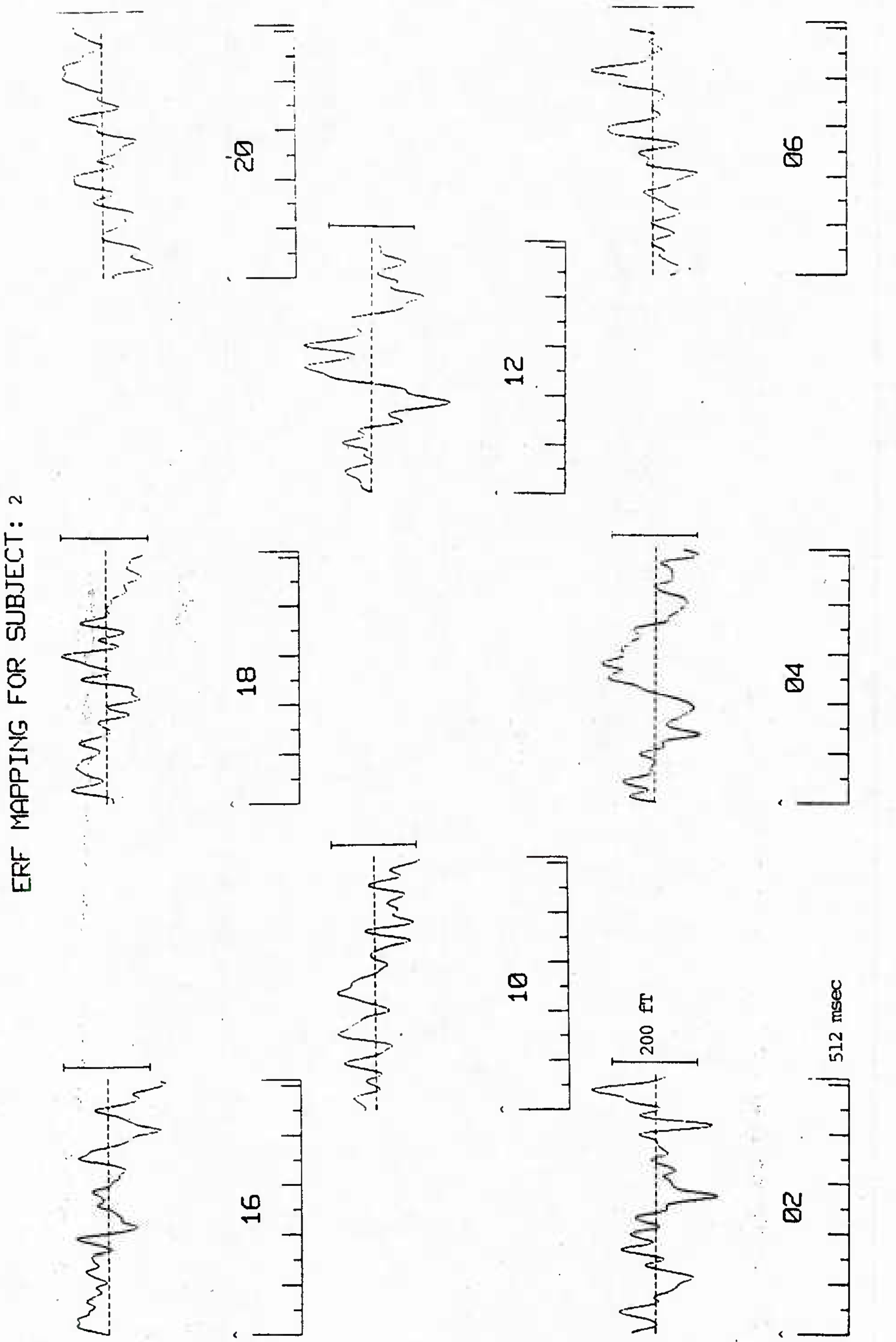
APPENDIX

VISUALLY EVOKED MAGNETIC FIELD TOPOGRAPHIC MAPS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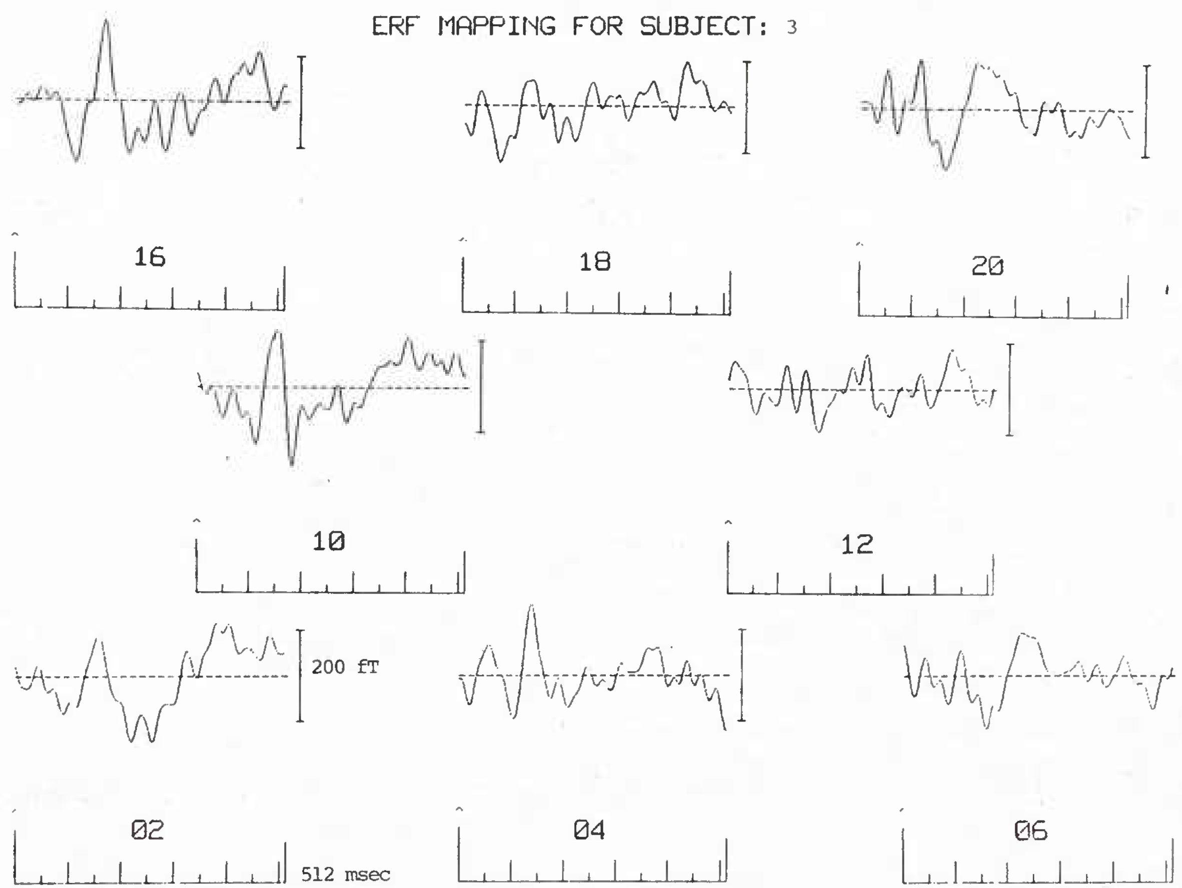
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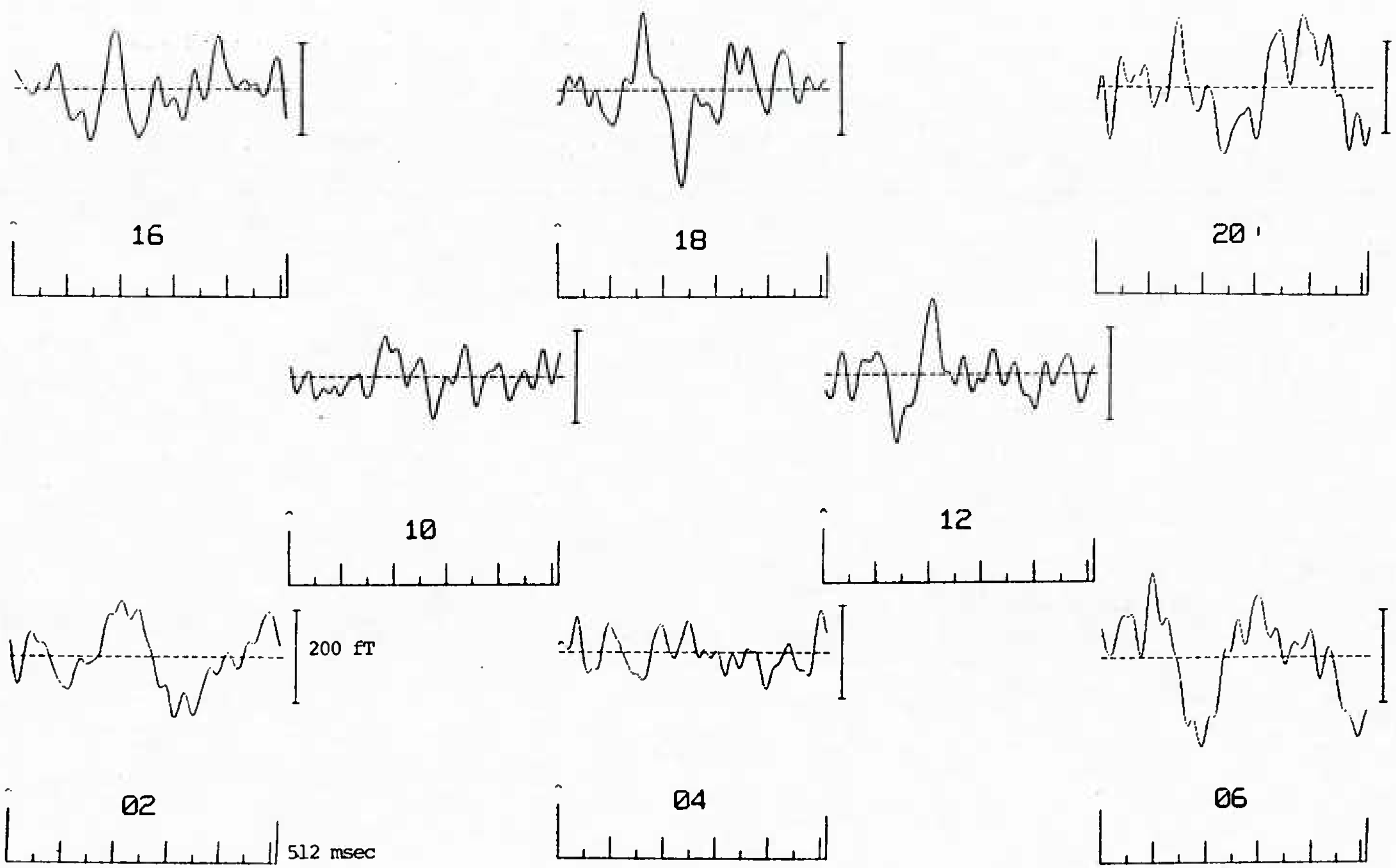

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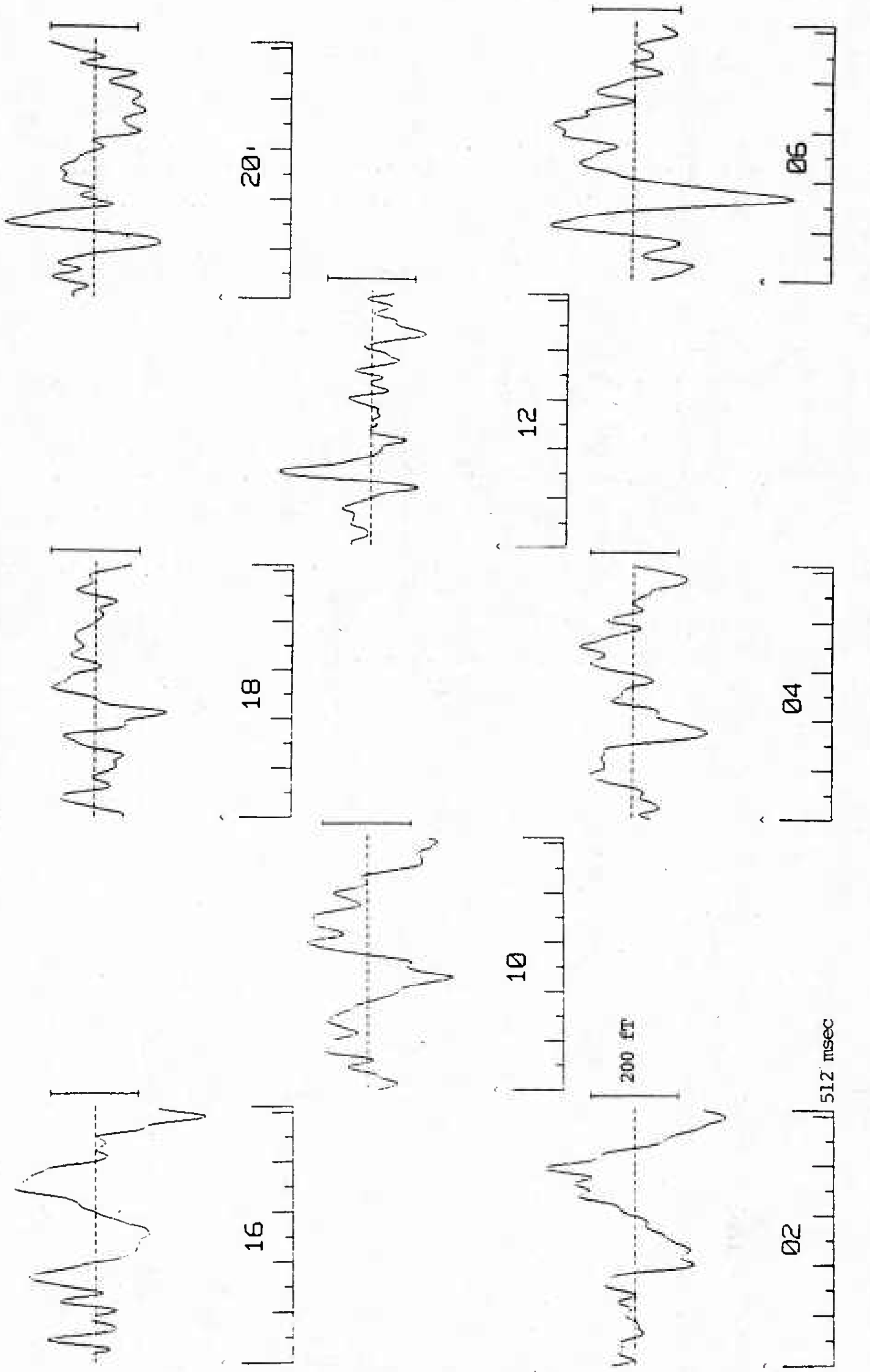

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